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THE PREDICTION OF MOBILITY GAINS IN CERVICAL SPINAL CORD INJURIES

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INTRODUCTION

The treatment of spinal cord injuries is a controversial subject among physicians[1,8,10]. The choice of a particular procedure depends on the location and severity of the injury as well as the physical condition of the patient. The effectiveness of the treatment is usually measured in terms of change in motor abilities during some specified recovery period. Mobility gain, however, has not been uniquely defined and there is no universally accepted concise measure of motor skills[2,3]. Further, few studies are available which analyze quantitatively motor actions as a function of patient characteristics and treatment procedures.

One innovation in improving this situation has been the establishment of registries to collect data on spinal cord injuries. Several national centers are in operation and are located at New York University, Yale University, Ohio State University, Barrow Neurological Institute, and the Medical University of South Carolina (MUSC). While these centers have different objectives, each has the goal of improving patient care. The National Spinal Cord Injury Registry (NSCIR) at MUSC, for instance, receives data from neurosurgeons throughout the United States and Canada and collects information on the early treatment of spinal cord injuries[6]. The data are collected in two phases: a comprehensive initial examination at the time of injury and a similar evaluation one year following the injury.

The objective of this paper is to discuss the prediction of motor skills among a group of patients whose records are at the NSCIR at MUSC.

A mobility index is developed and it is utilized in constructing a model for predicting mobility one year post-injury. Important predictor variables are also identified and discussed.

MOBILITY INDEX

The absence of any widely accepted measure of mobility for spinal cord injured persons has heretofore limited the inferences that could be made on patient status and response treatment[2,3]. One of the initial objectives of this investigation was the construction of a single mobility index. It was desired that this index be at least interval-scaled with zero implying the absence of any mobility and the maximum value indicating average movement of an uninjured person.

Accordingly, a motor exam was incorporated in the information reported to the NSCIR. This examination, given at the time of injury and also one year following the injury, included measurements on shoulder abduction, elbow flexion and extension, wrist flexion and extension, small hand muscles, intracoastals, abdominals, hip flexion and internal rotation, knee flexion and extension, and ankle dorsi- and plantar flexion. The right and left sides of the body were separately evaluated for the 14 motor variables during the initial and final exam.

The examining physician assigned a score of 0 to 10 to each of these 28 motor actions, where zero is the lowest possible score and implies no movement, and 10 is the highest permissible value corresponding to normal movement. Since overall mobility involves all parts of the body

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ABSTRACT

A measure of mobility for spinal cord injured persons is introduced that is very useful in determining patient recovery. The index is utilized to obtain a prediction equation for motor skills one year after injury. Important predictor variables identified include sex, rectal status, total reflexes, two treatment combinations, motor and sensory neurologic history since injury, neurologic status, and initial mobility score. Interpretations are made to explain the meaning of the contributions of these variables and show the usefulness of the prediction equation. Insight is given for better understanding the recovery ability of spinal cord injured patients.

[1]Part of this research was conducted while the first author was an Assistant Professor in the Department of Biometry at the Medical University of South Carolina.

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20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

A measure of mobility for spinal cord injured persons is introduced that is very useful in determining patient recovery. The index is utilized to obtain a prediction equation for motor skills one year after injury. Important predictor variables identified include sex, rectal status, total reflexes, two treatment combinations, motor and sensory neurologic history since injury, neurologic status, and initial mobility score. Interpretations are made to explain the meaning of the contributions of these variables and show the usefulness of the prediction equation. Insight is given for better understanding

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the recovery ability of spinal cord injured patients.

it was felt that the total motor score, ranging from 0 to 280, would be an adequate reflection of actual motor abilities. Moreover, since each patient would receive an initial and a final (one year post-injury) motor examination, an initial and final mobility score could be determined and mobility gains could be measured for each patient. Consequently, the described mobility index serves as the basis of the analysis of these spinal cord injured patients.

SAMPLE

The study sample consists of cervical spinal cord injured patients reported to the NSCIR between December 1971, and March 1974. This location on the spinal cord is used since cervical lesions cause severe neurological problems and early mortality is high among such patients[5,7,12,13,14,15]. Four-hundred-and-ninety-two patient records with cervical injuries were processed through the registry, but only 75 had complete and accurate initial and final examination data. These 75 patients are included in the present study.

The sample consists of 83% males with an average age of 28.2 years and 17% females with average age 26.5. The causes of injury in this sample are similar to the causes for the entire group of 492 cervical cord injuries, with the major cause being vehicular accidents (41%), followed by sports accidents (23%) and falls (20%).

To illustrate the range of mobility scores, Figure 1 is a scatter diagram of final (one year post-injury) versus initial (time of

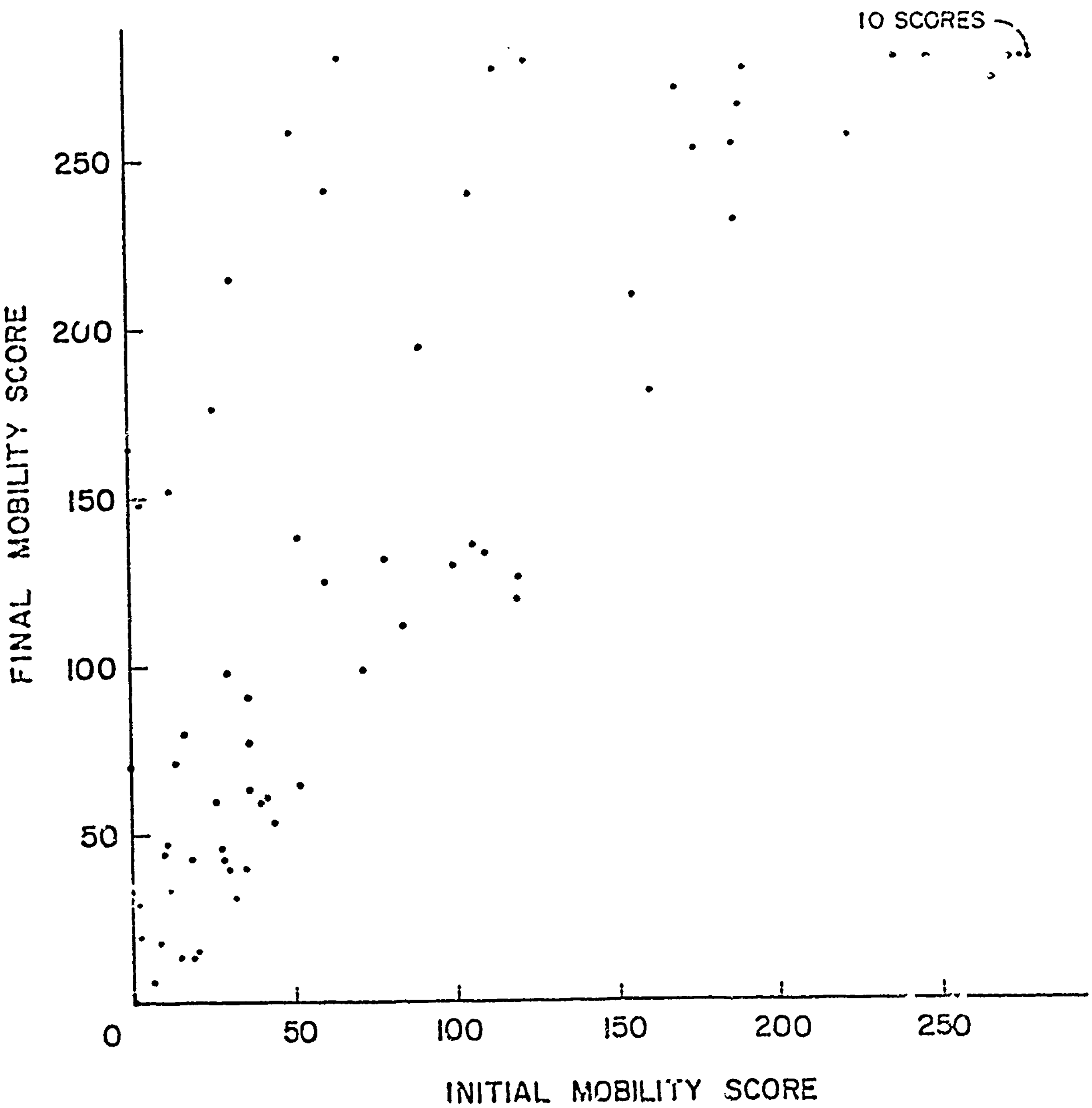

FIGURE 1. SCATTER DIAGRAM OF FINAL VS. INITIAL MOBILITY SCORES FOR INJURED SPINAL CORD PATIENTS (n=75)

initial examination) mobility scores. The scores are well dispersed throughout the upper portion of the diagram, indicating that virtually all these patients improved their mobility score although the amount of improvement is highly variable.

Figure 2 is a bar graph of the treatments used on patients included in this study. Immobilization (I) was prescribed singly in 40% of the cases and combined with procedures in over 80% of the cases. Approximately 30% of the patients received some form of medication (M) and 40% were treated with stabilization (S). Only 20% of these treatments involved the use of decompression (D) techniques.

The location of injury in the cervical portion of the spinal cord is depicted in Figure 3. The eight regions labeled C1 to C7 and T1 are actually C1, C1/C2 or C2, C2/C3 or C3, C3/C4 or C4, C4/C5 or C5, C5/C6 or C6, C6/C7 or C7, and C7/T1 or T1. Approximately three-fourths of the injuries were located on the C4, C5, and C6 regions of the spine with roughly an even distribution among the three. Nineteen percent of these patients were injured in the C1 to C3 regions while less than 10% of the injuries were in the C7 to T1 areas.

It is interesting to note that the majority of the injuries were moderately severe (C4 to C6) and thus required quick response (immobilization) followed by some type of treatment. Since both sexes were relatively young (between 20 and 40) this could account for the pattern that emerges.

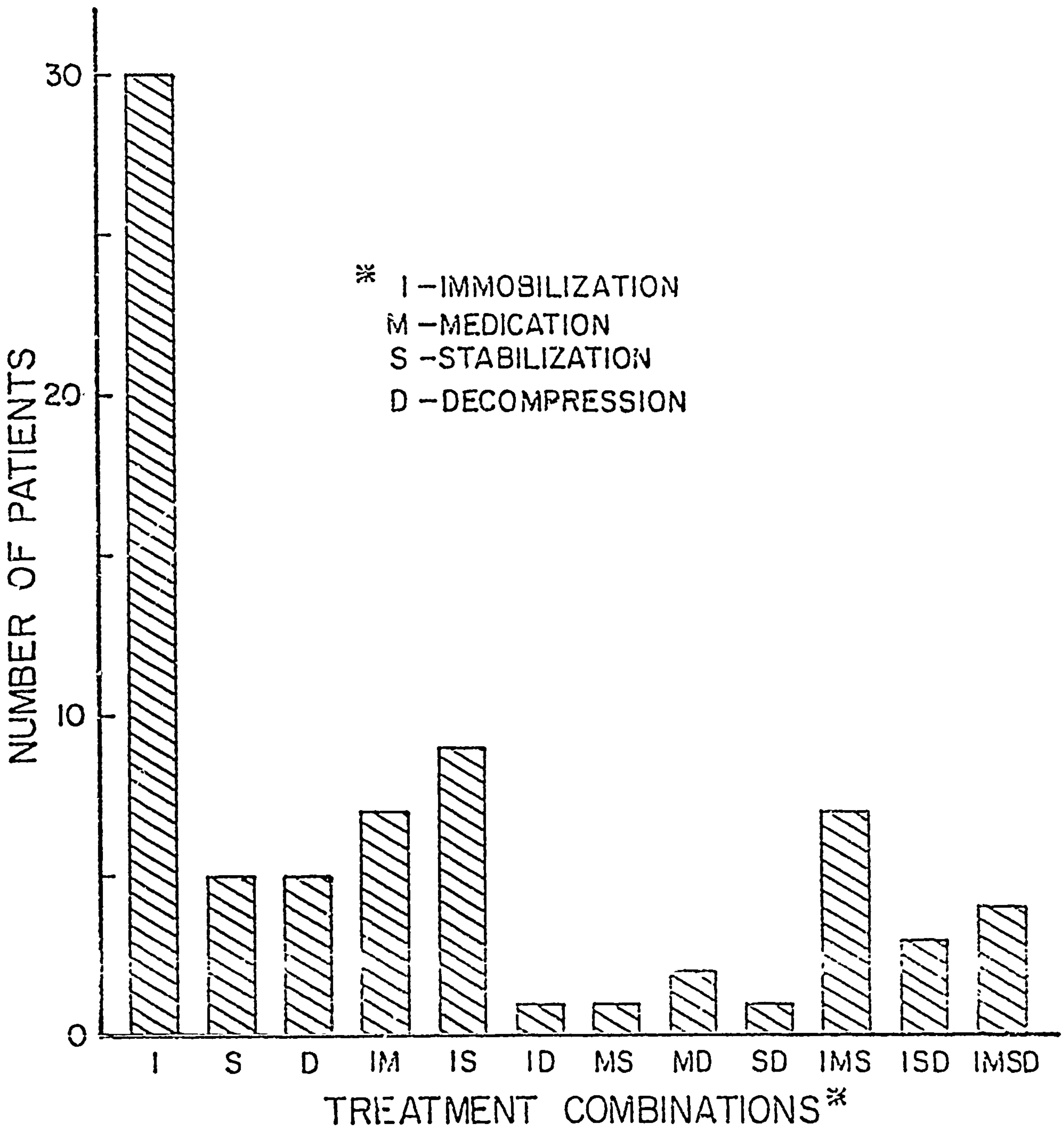

FIGURE 2. DISTRIBUTION OF TREATMENTS ADMINISTERED TO SPINAL CORD PATIENTS

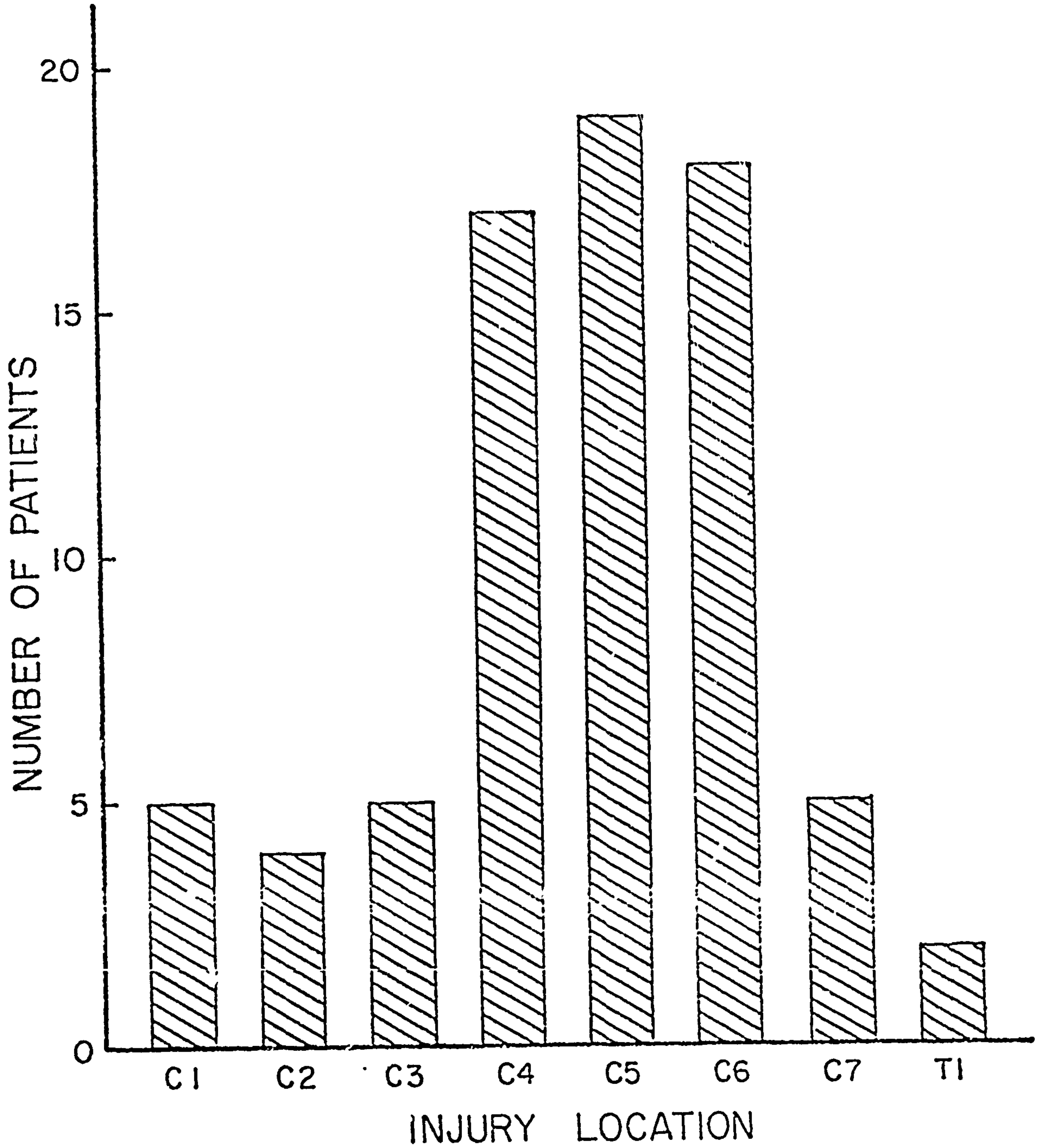

FIGURE 3. DISTRIBUTION OF LOCATION OF CERVICAL INJURIES

METHOD

The entire set of 25 variables extracted from the NSCIR initial examination included in this study are listed in Table 1. Sex and age are self-explanatory. Bladder condition, rectal status, neurologic status, and motor- and sensory-neurologic history since injury are categorical variables with a higher value indicating a more normal status. Twelve combinations of the four treatments listed in Table 1 were administered (these are shown in Figure 2). Location of injury assigned integer values 1-8 to the locations C1 to T1.

Gait characterizes the ability to support weight and walk or run. This variable is grouped into categories from 1 (unable to support weight) to 6 (normal ability to walk or run). Mechanism of injury records the cause of injury: fall, hit (other than by automobile), industrial accident, motorcycle accident, other (any injury not specifically stated in this group), pedestrian injury, penetrating injury, sports accident, and vehicle accident (other than motorcycle). Lowest dermatone intact level was measured by pin prick on the right and left sides of the body and assigned a numerical score from 0 to 30 (normal). These scores were then totaled to yield the total lowest dermatone intact level. Reflexes were likewise measured at several locations (biceps, triceps, brachioradialis, abdominals, knee, ankle) on the right and left side of the body, each being scored from 0 to 4 (normal). Total reflexes is the cumulative score on all these measurements. Finally, initial mobility score was defined in the previous section.

Table 1

Variables Measured in Initial Examination

No.	Description	Range
1	Sex	0-1
2	Age	13-73
3	Mechanism of Injury	2-10
4	Gait	1-6
5	Bladder Condition	1-3
6	Rectal Status	1-3
7	Location of Injury	1-8
8	Total Lowest Intact Dermatone Level	0-60
9	Total Reflexes	0-48
10-21	Treatments*	0-1
22	Neurologic Status	1-3
23	Motor-Neurologic History Since Injury	1-3
24	Sensory - Neurologic History Since Injury	1-3
25	Initial Mobility Score	0-280

* Immobilization (Tongs, Brace, Traction)
Medication (Steroids, Diuretics, Drugs)
Stabilization (Anterior Fusion, Posterior Fusion)
Decompression (Laminectomy, Anterior Decompression)

The twenty-five variables were used in a multiple linear regression model to predict final mobility. Recall that final mobility cannot exceed 280. Moreover, a patient with an initial mobility score near 280 cannot improve his mobility rating regardless of the treatment applied, again because the maximum mobility score possible is 280.

Due to this restriction in the data, the inclusion of patients with initial or final mobility scores of 280 would severely distort comparisons of treatments and prediction of mobility gains. For instance, immobilization was administered to 9 of 10 patients with initial scores of 280, each of whom cannot improve his mobility score one year later. This implies that immobilization was either applied routinely to these patients or as a precautionary measure. Moreover the lack of improvement (since none is possible) in these patients could suggest to the casual observer that immobilization is ineffective if, for example, the average difference in final and initial scores is examined for patients who are immobilized. Yet two more severely injured patients improved their mobility scores substantially (from 124 and 239 to 280) when immobilization was prescribed. Thus for all patients with a final mobility score of 280 one can question whether the effects of the treatments are being adequately represented.

Because of the above considerations, sixteen patients with final mobility scores of 280 were deleted and the remaining 59 patients were used to construct a prediction equation. It was felt that the usual assumptions surrounding the linear regression model would be adequately met with these patients and also that conclusions regarding the predictor variables would be more valid.

RESULTS

Several variable selection techniques[4], were applied to the 25 variable regression model in order to delete variables which did not contribute sufficiently to the prediction of final mobility. The results below are valid for prediction with patients whose initial mobility score adequately reflects the overall functioning of gait, bladder condition, rectal status, and reflexes, i.e., a high score indicates normal function, a low score indicates residual functioning of one of mo re of the variables. These inferences, in fact the prediction equation itself, may not be a valid representation of final mobility of patients not having the above relationship. For example, patients with high initial mobility scores yet low values for several of the above variables or patients with low initial scores yet normal functioning of all these variables are not included in this data. Such individuals may not exist or simply may not have occurred in this sample.

The variable selection procedures used suggested a ten variable model would adequately predict final mobility. The variable s chosen and their corresponding coefficients are displayed in Table 2. The equation resulted in a coefficient of determination of $R^2 = 0.755$ indicating that approximately 76% of the variability of the final mobility scores is accounted for by these variables.

DISCUSSION

The prediction equation reveals that if all other variables are held constant, females tend to have final mobility score approximately 37 points

Table 2

Ten Variable Predictor of Final Mobility

Predictor Variable	Estimated Coefficient	t Statistics
Constant Term	4.21	
Sex	36.68	2.16
Rectal Status	16.59	1.33
Total Reflexes	2.54	1.30
Treatment IM	-31.97	-1.58
Treatment IMSD	59.41	2.20
Neurologic Status	32.02	1.87
Motor - Neurologic History	-18.84	-1.35
Sensory - Neurologic History	13.87	0.77
Initial Mobility Score	0.53	2.37

higher than males. This phenomenon has been noted previously and linked to more severe depression in males, resulting in less response to treatment or therapy[7,14]. Rectal status, total reflexes, and initial mobility score all have positive coefficients indicating that more normal function in these variables increases the predicted final mobility score. In particular, a gain of control of the anal sphincter will usually imply a gain of motor function in the lower extremities[2]. The presence of reflexes and motor skills early after injury is a welcome sign and can aid the physician in his choice of treatments[11].

The negative coefficient on motor-neurologic history initially appears confusing. One would expect that larger values on this variable should contribute positively to predicting final mobility. The confusion is readily explained when one realizes that neurologic status, motor-neurologic history, and sensory-neurologic history are all related and should not be examined separately. Both motor- and sensory-neurologic history were categorized as worse, same, or better. Twenty-nine of the 59 patients scored "same" on both motor- and sensory-neurologic history and 15 scored "better" on both. Thus these two variables yield similar information for 75% of the patients. Of the remaining 15 patients, 12 are recorded as "same" on sensory and "better" on motor neurologic history.

Neurologic status was categorized as complete lesion, partial lesion, and normal (no lesion). "Same" on sensory and "better" on motor history coupled with neurologic status "complete" yields a net positive effect while using neurologic status "partial" results in an even larger change. Similarly for the 44 patients scoring "same" or "better" on both variables, the net effect of neurologic status and the two neurologic history variables is positive and increases with increasing values of neurologic status. This association seems justified since neurologic status describes the type of lesion which is an important factor in the recovery of a spinal cord injured patient[13].

The two treatment combinations in the predictor are immobilization and medication (IM) and immobilization, medication, stabilization, and decompression (IMSD). These variables are not retained because they are necessarily the best or the worst treatments, but due to the fact that they produce a different estimated final mobility score than the other treatment combinations. This point may be more clearly understood by considering the final and initial mobility scores given in Table 3.

Comparing these values with scores for other treatment combinations reveals three things: (i) all other treatment combinations are much more variable on each mobility score, i.e., there are several large and small scores for initial and final mobility with every other treatment combination; (ii) the initial mobility scores for both treatments in Table 3 are all quite low; and (iii) treatment IM has predominantly low scores on the final mobility measurement while treatment IMSD has predominantly high scores for final mobility. Thus the variability of all other treatment combinations causes the effects of these treatments to be indistinguishable. Treatment IM was used with patients having predominantly low initial and final mobility scores, while IMSD was utilized with patients who had predominantly low initial scores and high final scores.

Table 3

Comparison of Initial and Final Mobility Scores for Patients Receiving Treatment Combinations Remaining in the Final Prediction Equation

IM		IMSD	
Initial Score	Final Score	Initial Score	Final Score
40	60	62	241
0	34	41	61
52	65	90	195
14	15	31	215
19	14		
6	6		
60	125		

Note from Table 2 that treatment IM has a negative coefficient while treatment IMSD has a positive one. Hence, treatment IM would produce a lower value to the prediction of final mobility than any other treatment, while IMSD would yield the largest contribution to the predictor. The reader should be careful not to interpret this as implying that treatment combination IM is the poorest and IMSD is the best combination for spinal cord injuries. The patients were not assigned to the treatment groups randomly and each of the other treatment combinations produced some substantial improvement in patients.

In summary, a mobility measure was introduced in this paper that is very useful in predicting patient recovery. This index was used to obtain a prediction equation for motor skills one year after injury.

The coefficients in Table 3 seem reasonable and the prediction equation is adequate ($R^2 = .755$). A physician could thus use the results of an initial examination in combination with this equation to gain insight into the recovery abilities of spinal cord injured patients. Specific attention would be directed to patient sex, rectal status, total reflexes, motor and sensory neurologic history since injury, neurologic status, and initial mobility score. Choice of treatment and care could then be determined so as to best affect the motor recovery ability of the patient.

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KEY WORDS

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